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COBALT

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PAUL M. TYLER

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DEPARTMENT OF COMMERCE - BUREAU OF MINES

COBALT[1]

By Paul M. Tyler[2]

CONTESTS

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1 The Bureau of Mines will welcome reprinting of this article, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6331."

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INTRODUCTION

One by one new metals come forward to share the burden of modern industry. Long before the Christian era potters and glass workers employed fine and costly blue pigments that contained cobalt. Cobalt blue glass has been found in the tombs of the Egyptians and in the ruins of Troy, and many of the colors used by the ancient Greeks and Romans contained cobalt. The ancients, however, were apparently unaware that the colors they used were caused by cobalt, and it was not until late in the 17th century that the existence of the element was recognized. Writers in the Middle Ages referred to "cobalos" as an evil spirit that haunted mines and caused trouble to the miners. Subsequently the German work "Kobold," meaning goblin, came to be applied to any baffling mineral and particularly to minerals that resembled ores but failed to yield metal when smelted. Even to-day there is something of an air of mystery about cobalt, and a medieval cloak of secrecy still surrounds many of the metallurgical processes employed in its production.

"Zaffre" was mentioned about the middle of the sixteenth century by Biringuccio, and in 1735 the metal was first prepared by G. Brandt. The preparation of cobalt compounds, however, must have been carried on in at least a small way ever since the opening of the silver-cobalt deposits of Schneeberg in 1470. By 1790 there were 25 works engaged in the industry, most of them located in Saxony, but the total output of these works probably did not exceed 300 tons of cobalt annually, mostly in the form of smalt. The smalt which contained approximately 6 per cent cobalt was sold in Venice in 1520 at about 16 cents a pound. A few refineries in Holland supplied the Irish linen trade, contributed a large amount to the Dutch linen industries, and also provided smaller quantities for the manufactuer of litmus in Holland. A complete description of the early history of the cobalt industry in Saxony, is given by Mickle in the Report of the Bureau of Mines of Ontario, vol. 19, 1913, pt. 2, pp. 234-251.

Smalt is used now only in a few enamel works. It is a blue compound which owes its color to the presence of cobalt silicate, but as formerly prepared it contained various impurities. The oxides of cobalt are now preferred in the ceramic industry because of their purity, uniformity, and lower cost.

Only within the last two decades has cobalt found extensive application outside of the glass and pottery industries.

DESCRIPTION

Cobalt is a silvery white metal strongly resembling nickel in its appearance and properties. The atomic weight (58.94) is a trifle higher than that of nickel (58.69), but in the periodic system it is actually placed before nickel because chemically and physically it is intermediate in its properties between iron and nickel. According to Mellor, the specific gravity is 8.5; the atomic volume, 6.94; and the melting point, 1,467° C.[3] Drury[4], however, gives the specific gravity as ranging from 8.79 on an unannealed sample to 8.92 on a swaged

3 Mellor, J. W., Modern Inorganic Chemistry: London, 1918, p. 501
4 Drury, Charles W., Cobalt, Its Occurrence, Metallurgy, Uses and Alloys: Rept. Ontario Bur. Mines, 1918, vol. 27, pt. 3, Sect. 1, p. 70.

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sample and the melting point as being 1,478° C. The tensile strength is quoted by the latter authority as being 34.400 pounds per square inch. Cobalt is magnetic, more so than any other metal except iron. When reduced from the oxide it is in the form of a gray powder.

The metal is soluble in dilute acids. It forms two series of compounds. Cobaltous compounds (bivalent) are yellow or green in the anhydrous state but form pink crystals and are pink in aqueous solutions, turning blue, however, in the presence of strong hydrochloric acid. No simple cobaltic salts have been prepared, but cobalt is trivalent in potassium cobaltinitrite and other complex compounds, including a variety of cabalti-ammonia derivatives. There are three oxides: cobaltous oxide (CoO), greenish gray; cobaltous-cobaltic oxide (Co_3O_4), black; and cobaltic oxide (Co_2O_3), brownish. These may be prepared by heating the cobaltic hydroxide at a red heat, but when any of the three oxides is dissolved in acid, only cobaltous compounds are formed. Precipitated cobaltous hydroxide, however, gradually turns brown in contact with the air, forming cobaltic hydroxide. In the absence of ammonium salts ammonia precipitates a blue basic salt, but this is soluble in excess of ammonium chloride. The dirty yellow ammoniacal solution slowly becomes reddish on exposure to air, forming stable cobalti-ammonia salts: $Co(OH)_2 + 2NH_4Cl + 2NH_3 = Co(NH_3)_4\ Cl_2 + 2H_2O$. Complex cations and anions containing cobalt are very numerous and very stable.

USES

Cobalt is used both in the form of the metal and in the form of the oxide and other compounds. In the United States, metallurgical uses account for fully 50 per cent of the total, and probably not more than about one-third of the consumption is now absorbed in the ceramic and chemical industries.

The largest single use of cobalt is in the cobalt-chrome series of alloys known as "stellite." These nonferrous alloys--often modified by the addition of tungsten, molybdenum, and other metals--are widely employed to replace tool steel and for other purposes in which hardness and strength (even at a red heat) combine with corosion resistance are desired. Substantial amounts of cobalt metal are used in magnet steels, tool steels (including high-speed steel), and certain rust-resisting steels. Some magnet steels contain as much as 60 per cent cobalt. Small quantities have been used in electroplating. A new metal, called "Konel" and containing cobalt, nickel, and ferrotitanium, is claimed to be a satisfactory substitute for platinum in many of its uses. It was originally developed for use in filaments for radio tubes, but since it is harder than cold steel even when it is red hot, it seems well-adapted for a variety of uses. It may find extensive employment in the moving parts of internal-combustion engines and in other hot places. Another interesting use of cobalt, though one which does not afford an outlet for any substantial tonnage, is as a binder for tungsten carbide, the super-hard tool material which has gained wide recognition since it was first introduced

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in the latter part of 1928. This remarkable material, surpassed only by the diamond in hardness, will cut a screw thread in a glass rod, machines porcelain, and retains a keen edge even when forming mica board or ivory. A little cobalt is used in certain electrical resistance alloy wires and even in bearing metal.

Next to stellite, probably the main consumption of cobalt is in the ceramic industry where the oxide is used not only in colored ware but quite generally in the glaze of white ware, much as bluing is employed in laundering white clothing. As a body stain, likewise, cobalt is used to convert the yellow or slightly orange tint caused by traces of iron, in the proportion of about 1 pound of cobalt oxide to 1 ton of clay. In the aggregate a very substantial amount of cobalt oxide is used in the manufacture of cobalt acetate, oleate, borate, linoleate, tungstate, and oleoresinate used as driers in paint and varnish. In linseed oil paints, the acetate is widely used, the proportion usually ranging between 0.2 and 0.4 per cent.

MODE OF OCCURRENCE

Cobalt is not found native and is nowhere mined except in conjunction with other metals. In Cobalt, Ontario, the leading metal is silver, and in addition to cobalt, nickel and arsenic are present in the ores. In the Belgian Congo, cobalt is only a minor constituent of the copper ores. Bismuth is the most important constituent of the cobalt ores of Schneeberg, Germany. The New Caledonian deposits have been worked mainly for cobalt, but even there the cobalt is associated with manganese.

The commonest cobalt minerals are linnaeite (Co_3S_4, generally containing also some nickel and iron), smaltite ($CoAs_2$), cobaltite (CoAsS), and erythrite ($Co_3(AsO_4)_2.8H_2O$). Erythrite has a beautiful and quite characteristic peach-blossom color, but the first three minerals mentioned are silvery-looking and not easily distinguishable from several other minerals having a metallic lustre. Manganese ores containing cobalt have a characteristic blue lustre on the fresh, dry fracture. Such ores ordinarily contain 5 per cent or less of cobalt, but the writer has found samples containing 15 per cent of cobalt and 35 per cent manganese in the southern United States.

IDENTIFICATION

Even a small quantity of cobalt imparts an intense blue color to a borax or salt of phosphorus bead, both in an oxidizing and in a reducing flame. If copper or nickel interferes, the bead may be heated on charcoal in a reducing flame with a granule of tin, thereby reducing the nickel or copper to the metallic state and enabling the characteristic blue color of the cobalt to be seen. Iron in quantity sufficient to interfere may be removed in the wet way, but it is generally possible to detect the presence of even a fraction of 1 per cent of cobalt in either iron or manganese ores, provided only minute quantities of the material are taken up in the bead and provided the color of the iron or manganese is reduced to a minimum by prolonged heating in the reducing flame.

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METALLURGY

Arsenical ores, such as those from Cobalt, Ontario, are usually smelted in a blast furnace to form a speiss, and this speiss, a mixed arsenide of iron, cobalt, and nickel, is later roasted to remove the bulk of the arsenic which is saved as a by-product. The residue, usually containing about 10 per cent arsenic and from 20 to 30 per cent or more cobalt, is reserved for treatment by wet chemical processes.

The separation of nickel from cobalt is the only phase of the treatment that presents unusual features. Calcium hypochlorite (bleaching powder) solution added to the clear chloride solution (freed from arsenic, iron, and copper) precipitates the cobalt in the form of black cobaltic hydroxide, $Co(OH)_6$. Nickel does not precipitate unless an excess of the hypochlorite is used; it is recovered from the filtrate by adding milk of lime. The filtered cobalt oxide when dried and gently calcined, carries 76 to 77 per cent of the element. A newer process for separating nickel and cobalt is described briefly by Dyson[5]. It involves the reactions of complex ammonia compounds. An ammoniacal solution containing cobalt chloride is oxidized by hydrogen peroxide (or merely by blowing air through it) so as to form what is known as roseocobalt chloride, the formula of which is $[Co(NH_3)_5.H_2O]Cl_3$. This aquo-pentamino-chloride when boiled is converted into chloropentamino-chloride or chloropurpureocobalt, having the formula $[Co(NH_3)_5.Cl]Cl_2$.

Manganese is another interfering element. There is practically no manganese in the cobalt ores found at Cobalt, Ontario, but practically all the cobalt ores from New Caledonia, previously in large use, carried a high percentage of this metal. In the manipulation of the New Caledonia ores, the cobalt and nickel were precipitated together by means of sodium sulphide, leaving practically all of the manganese in solution.

Various other means have been devised for getting the cobalt into solution, and despite the secrecy that has surrounded most cobalt enterprises, the number of processes described in the literature is legion. Details of a variety of such methods will be found in the excellent review by Drury[6] published by the Ontario Bureau of Mines.

Metallic cobalt, according to this report, may be obtained by:

(1) Reduction of the oxide in a carbon crucible or by added carbon (or starch).

(2) Reduction of the oxide or oxalate in a stream of hydrogen or hydrocarbons, the reduction being complete at 500 to 600°C.

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5 Dyson, G. Malcolm, The Extractions and Utilizations of Cobalt: Chem. Age, vol. 19, Nov. 3, 1928, pp. 33-34, Mon. Met. Sec.

6 Drury, Charles W., Cobalt, its Occurrence, Metallurgy, Uses and Alloys:. Rept. Ontario Bur. Mines, 1918, vol. 27, pt. 3, pp. 31-69.

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(3) Reduction of the oxide by carbon monoxide.

(4) Reduction of the oxide by ammonium chloride.

(5) Reduction of cobalt chloride in a current of hydrogen.

(6) Reduction of the oxide by aluminum (Goldschmidt or thermit process).

(7) Precipitation from cobalt solutions by metallic magnesium or zinc.

(8) Distillation of cobalt amalgams.

(9) Electrolytic methods.

WORLD PRODUCTION

Early in the nineteenth century the limited supply of cobalt (in the form of smalt or zaffre) came from Norway, Sweden, and Saxony. Later, New Caledonia became the chief producer. Early in the twentieth century practically all of the world's cobalt began to come from the newly-discovered silver-cobalt-arsenic ores of Ontario, and for some time the potential supply as a by-product of silver production far exceeded the demand. An active search for new uses, however, soon resulted in increased sales. By 1926 the Belgian Congo, which produces cobalt as a by-product of copper, had become a close rival of Ontario and even forced a temporary curtailment in Canadian production. At present more than half of the world production comes from the ores of Cobalt, Ontario. The metal and its oxide are produced chiefly in Canada, Great Britain, and Belgium from ores mined in Ontario, Belgian Congo, and Queensland. Germany's contribution is rather small, though the mines in Saxony are still productive and cobalt residues and ores are purchased abroad for treatment in German works. The United States, though by far the leading consumer, is an unimportant factor in production.

The cobalt production data published by the several producing countries are given in such indefinite figures that the estimates are far from exact. According to Drury[7] the world's annual output of cobalt oxide previous to 1913 amounted to approximately 250 tons. In 1916 it increased to 400 tons but shortly after the outbreak of the World War the production of cobalt metal increased from practically nothing in 1913 to 165 tons in 1916 and 158 tons in 1917. The following figures (Table 1) have appeared in the annual chapters of Mineral Resources:

7 Loc. cit., p. 31.

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Table 1.- World production of cobalt, 1924-1929, in metric tons[1]

Country	Cobalt-bearing material	1924		1925		1926		1927		1928		1929	
		Gross weight	Cobalt content	Gross weight	Cobalt content	Gross weight	Cobalt content	Gross weight	Cobalt content	Gross weight	Cobalt content	Gross weight	Cobalt content
Australia: Queensland	Cobaltite, concentrates, etc.	200.4	[2] 60	417.6	91.4	137.2	27.4	- -	- -	40	8	(3)	(3)
Belgian Congo	Copper-iron-cobalt alloy	976	[2] 273	684	[2] 192	794	[4] 360	2,100	[5] 588	(3)	[4] 450	(3)	(3)
Canada: Ontario	Cobalt, alloys, and chemicals	(3)	209.2	665	246.1	794	302	(3)	599	(3)	434	(3)	422
Chile	Arseno-sulphide ore	34.6	2.1	- -	- -	6.4	(3)	(5)	(6)	11	2	(3)	(3)
China: Yunnan	(3)	- -	- -	[5] 250	(3)	[4] 250	(3)	[5] 250	(3)	[4] 250	(3)	[5] 250	(3)
Germany: Saxony	Cobalt-bismuth-nickel ores	102	[2] 6	145	6.9	155	[2] 7.4	92	(3)	82	(3)	(3)	(3)
India, British: Burma[7]	Cobaltiferous nickel speiss	- -	- -	- -	- -	- -	- -	4,770	167	3,378	136	3,834	134
New Caledonia	Concentrates[8]	- -	- -	- -	- -	- -	- -	[9] 78.6	[5] 3.5	(3)	(3)	(3)	(3)

1 Mineral Resources of the United States, U. S. Bureau of Mines; statistics compiled by L. M. Jones. Figures not available prior to 1924.
2 Estimated. The Belgian Congo alloy is said to carry 28 per cent of cobalt.
3 Data not available.
4 Cobalt in metal, oxide, and salts produced at Oolen, Belgium.
5 Estimated.
6 Less than 1 ton (471 kilograms).
7 Year ended June 30, of year stated.
8 Cobalt-bearing manganese oxide.
9 Exports.

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DOMESTIC PRODUCTION AND DEPOSITS

Statistics are available showing a production of cobalt oxide in the United States year after year from 1869 to 1904, inclusive. Most of this was recovered in refining the copper-nickel ores of Sudbury. From 1905 to 1913 during the operation of the cobalt plant (a few hundred yards south of its main nickel-copper smelter), of the Canadian Copper Co. (International Nickel) at Copper Cliff, Ontario, a total of perhaps 2,500,000 pounds of cobalt was separated and purified in this country.[8] Previous to 1900, the Mine la Motte Co. shipped cobalt ore to Swansea and in 1903 produced 120,000 pounds of oxide in a Missouri plant. Another cobalt refinery erected in 1906 by the North America Lead Co. at Fredericktown, Mo., operated intermittently until 1910. In 1909 it produced 83,384 pounds of cobalt oxide, 328,403 pounds of nickel, 8,314 tons of nickel-cobalt concentrates, 600 tons of copper concentrates, and 1,353 tons of lead concentrates. This plant was purchased at a forced sale in 1915 by the Missouri Cobalt Co., which produced a certain amount of oxide in 1918 and in 1920 recovered 102,410 pounds of cobalt oxide and cobalt hydrate, valued at $262,801. It then closed down.

Oregon has been credited with spasmodic shipments of arsenical ore containing cobalt, gold, and silver; a few tons were sent to France in 1905. Nevada, also, has produced one or two carloads of cobalt ore. In 1917 the Haynes Stellite Co., a large consumer of cobalt, began mining at Blackbird, Lemhi County, Idaho, where a large number of veins were said to contain cobalt. Prospecting and concentrating experiments were carried on for two or three years, but since 1921 nothing further seems to have been done in this district.

Cobalt occurrences have been reported in at least 12 States, and various attempts have been made to open them up, but beyond spasmodic outputs from Missouri, Idaho, Oregon, and Nevada, there has been practically no commercial production. It is only fair to say, however, that there has been little incentive to develop cobalt properties, and for this reason a brief review of reported occurrences may be of interest.

Alabama.- Manganese ores containing cobalt have been found near Rock Run, Cherokee County. At one locality a total of about one carload of 4 per cent ore was taken out, some of which was shipped for making ferromanganese. The cobalt content, of course, was lost.

Alaska.- During the summer of 1922 a little erythrite was found in a narrow vuggy quartz vein on Hot Springs Dome near Hot Springs, on the lower Tanana River.

Arizona.- Specimens of erythrite containing kernels of cobaltite or smaltite have come from the Fort Apache Reservation, 50 miles north of Rice. A large deposit ($4\frac{1}{2}$ miles long and from half a mile to a mile wide) of nickel and

8 From 1906 to 1913, inclusive, the Canadian Copper Co.'s cobalt plant produced 2,318,916 lbs. of metallic cobalt contained in crude oxides shipped to the United States.

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cobalt has been reported 36 miles north of Tucson, and a small vein of cobalt was reported to have been found in 1927 on the 200 level of a mine in Pinal County, across the canyon from the old Silver King property. According to S. F. Wright (Engineering and Mining Journal, Dec. 1, 1928), "Arizona can boast of the best and perhaps the only real cobalt field in the United States. The veins are from 1 inch to 3 inches thick, and the ore assays from 29.45 to 49.15 per cent cobalt. As yet the owners have done nothing but prospect."

California.- The Mar-John Mining Co. in recent years has prospected a deposit of cobaltiferous arsenopyrite on a claim known as the "Hauselt Patent," 2 miles southeast of Sheepranch, Calaveras County. In addition to cobalt the ore is said to contain a sundry rare earths and other metals.

Colorado.- As early as 1882 smaltite was reported near Gothic, Gunnison County. A more recent find of cobalt-nickel ore was reported in 1929 by the Clark Mining Co., operated in the East Fork district; the vein is said to be about 6 feet wide.[9]

Connecticut.- About the middle of the nineteenth century there was a small production of arsenical cobalt-nickel ores from Great Hill, known locally as Cobalt Mountain, between Middletown and Middle Haddan. The railroad station still goes by the name of Cobalt. Little trace of the mining operations now remains. The ore is chloanthite, but evidently the quantity was too small to pay for working.

Idaho.- For several years, beginning about 1917, the Haynes Stellite Co. of Cocomo, Ind., mined and experimented upon cobalt ore in the narrow valley of Blackbird Creek, Lemhi County, Idaho. Work on these properties was eventually discontinued, but the following description by Hess is of interest:[10]

"Haynes Stellite Co.'s property, composed of two groups of claims, 30 claims in all, 21 of which were formerly owned by J. M. Beliel, the main group (Haynes Camp) being on the north side of the main creek, about 4 miles above its mouth and about 2 miles below the old mining camp of Blackbird, and the other group 2 miles southeast, on the West Fork of Blackbird Creek: The deposits are in a banded, thin-bedded, very fine grained gray and black quartzite, with some interbedded dark-green schist. Both rocks are very resistant to weathering, so that the valleys cut through them are narrow, with steep walls buttressed by great accumulations of sharp-edged talus lying at angles as great as 41°. Narrow zones in the quartzite have been shattered, and in these zones solutions have deposited quartz, tourmaline, and minerals containing cobalt combined with arsenic and sulphur, probably mostly cobaltite, the arsenosulphide (CoAsS), as indicated by the pinkish color; there is also some smaltite, the arsenide ($CoAs_2$). It is probable that arsenopyrite (the iron arsenosulphide, FeAsS) is also present, and, as shown by the green efflorescence

9 Denver Min. and Financial Rec., vol. 39, May 25, 1929, p. 1.
10 Hess, F. L., Cobalt, Molybdenum, Nickel, etc.: Mineral Resources of the United States, 1917, pt. 1, U. S. Geol. Survey, 1921, pp. 899-901.

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or "bloom" (annabergite) in some places on the outcrops, nickel is present in small quantity.....The tourmaline in the veins on these claims is in crystals so minute that they are indistinguishable to the unaided eye; consequently, tourmaline was not recognized in the field. It forms so large a part of the gangue that the vein is black and can not ordinarily be told from the country rock. Most of the particles of cobalt minerals are so minute that they can not be seen in the rough rock, and whether ore or barren rock is at hand can be ascertained, at least by the inexperienced, only by crushing and panning. The country rock is hard and dense, but the vein matter is harder and denser, and this in itself gives some guidance to the miner in places where the infiltration of vein matter has been insufficient to make its characteristics visible. Such masses weather more slowly and stand out from the quartzite and schist. Microscopic measurements of the minerals from these claims showed many grains to be less than 0.01 millimeter (0.0004 inch) in diameter; probably most of the grains in specimens collected by the writer are about 0.03 millimeter (0.0012 inch) in diameter, and the larger grains reach 0.25 millimeter (0.01 inch). In places, however, the grains are of the size of popcorn or even larger, but these are exceptional. It is claimed that the ore as mined gave, in an experimental mill run before the property changed hands, more than 1 per cent of cobalt. . . .

"At Blackbird a large number of veins carry cobalt minerals. Here the veins are in schists and gneisses as well as in quartzites. They contain less tourmaline, larger particles of cobalt minerals, more nickel, and so much copper that considerable money has been spent in prospecting for that metal. . . . Quartz veins reach a thickness of 10 feet, with subsidiary veins through a further thickness of 5 to 10 feet. Here and there, tourmaline is found in visible crystals. No mill test has been made of the numerous properties for cobalt, but it seemed probable that some of the properties, to be selected by sampling, would be well worth testing if there is sufficient demand for cobalt. There is much more nickel, as well as very much more copper in the ores immediately around Blackbird, and in most of the deposits the particles of cobalt minerals are very much coarser than at Haynes Camp. At Blackbird the Gray Eagle, owned by Wiley J. Rose, and other claims are located on a vertical crushed zone about 5 to 12 feet thick in schist on the northeast side of and parallel to Meadow Creek, one of the forks of Blackbird Creek. Where cut by a prospect tunnel on the Gray Eagle, this crushed zone strikes N. 40° W., and is in schist impregnated with quartz, which makes a very tough mass 10 to 12 feet thick that carries cobalt minerals. Ten feet southwest, pyrrhotite is found in bunches not over 6 inches thick, but on the St. Joe claim, adjoining the Gray Eagle claim on the northwest (owned by John E. Dubois, Dubois, Pa.), pyrrhotite 6 feet thick is said to have been cut at a depth of 100 feet and again at 250 feet, and is also said to have carried $18 a ton in gold and some cobalt and nickel. The dumps on these claims where wet by Meadow Creek are nearly covered with the beautiful peach-bloom pink erythrite (cobalt arsenate)."

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Cobalt has also been reported in Kootensi and Latah Counties, Idaho.

Maryland.- A sample of gahnite found at Mineral Hill mine, Carroll County, in 1923, showed the presence of 1.48 per cent cobalt oxide.

Missouri.- Near Fredericktown, in southeastern Missouri, occur the chief commercial deposits. In the Flat River district, to the northwest of the Fredericktown area, cobalt and nickel sulphides are sometimes recovered as a middling product. The following description of the Fredericktown deposits is quoted from the chapter on rare metals in "Mineral Resources of the United States, 1917:"

"The cobalt-bearing deposits of southeastern Missouri: The sulphides of cobalt and nickel occur associated with the sulphides of lead, iron, and copper in certain parts of the disseminated lead region of southeastern Missouri. The chief deposits of commercial value occur near Fredericktown, in the southern part of the region. In the Flat River district, to the northwestward of the Fredericktown area, cobalt and nickel sulphides are occasionally recovered as a middlings product on the tables of the lead mills and shipped to smelters for refining. The ore bodies in the vicinity of Fredericktown occur in the lower part of the Bonneterre dolomite and in the underlying LaMotte sandstone. The ore consists of a mixture of lead, copper, cobalt, nickel, and iron sulphides. The sulphides other than that of lead occur in greatest quantity in the lower part of the workings, next to and in the sandstone, especially near the granite and porphyry. The quantity of cobalt and nickel sulphides varies considerably in the different working. . . At Mine LaMotte, cobalt and nickel have been produced in small quantities for many years, even prior to 1857. . . . the chief source of the nickel and cobalt was the dressed galena, which usually carried from 0.2 to 0.3 per cent of these metals. Next in importance was a middlings product of the concentrating plant, which usually carried 20 to 23 per cent lead, 0.5 to 1 per cent of copper, and 2.5 to 3.5 per cent of cobalt and nickel. A larger percentage of copper was accompanied by a correspondingly larger percentage of cobalt and nickel. Besides these products of the mill, a small quantity of true cobalt-nickel ore was produced. In recent years, developments in the deeper workings have disclosed the presence of extensive deposits of copper-cobalt-nickel ore. The chief source of cobalt and nickel in Missouri has been the mine of the North American Lead Co., adjoining Fredericktown. From 1900 to 1906 this property was operated as a lead mine. In exploiting the property large quantities of copper, nickel, and cobalt sulphides were found associated with the lead sulphide. . . . Owing to the complexity of the ore, serious difficulties were encountered in both milling and smelting operations. In 1907, the company succeeded in producing 2,731 pounds of cobalt oxide. In 1909, 83,394 pounds of cobalt oxide, 328,403 pounds of nickel, 8,314 tons of nickel and cobalt concentrates, 600 tons of copper, and 1,353 tons of lead concentrates were produced. . ."

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Nevada.- Occasional shipments of cobalt have come from Nevada. In 1921 a carload of heterogenite was shipped from Good Springs, Clark County. "Rich mines" of erythrite are reported in the northeast part of Churchill County and this same mineral has been mined at the Lovelock mine, Cottonwood Canyon, Pahute Range, Humboldt County.[11]

North Carolina.- The United States Geological Survey, in a report for 1897-98, reported ores with a small percentage (0.03 per cent) of cobalt in the Dannemora mine, Rockingham County.

Oregon.- A. E. Kellogg[12] describes the cobalt deposits in Jackson County as follows:

"About twenty years ago cobalt was discovered in Jackson County, Ore., by Dr. W. P. Chisholm, of Gold Hill, Ore., the pioneer of the quicksilver industry in that district, while he was developing his gold-copper mine in the 'Meadows', twelve miles north of Gold Hill. This property, known as the Chisholm group, is still owned and under development by the doctor. It is situated not far from Chisholm's quicksilver properties, also in the 'Meadows'. Early in the development of the gold-copper property, large orebodies were opened up, which, besides producing gold and copper, also carried from 4 to 4½ per cent of cobalt. This work extended over a period of several years and it is estimated that at least 30,000 tons of this ore will produce not less than 4½ per cent cobalt.

" . . .Development of the quicksilver properties shows that the cinnabar ore, besides producing gold, silver, nickel, zinc, and arsenic as by-products, also gives evidence of cobalt values. Other localities in this region are believed to contain cobalt in commercial quantities, but the Chisholm mine is the only property in the district that has been reliabily and systematically tested for cobalt.

"The Chisholm mine is in a heavily timbered district, at an elevation of 1,760 feet. About $45,000 has been spent in its development. In part, the ore is a primary constituent of the norite country rock, and the vein deposits were probably derived from the same source. . . . .

"The Gold Hill district is a mountainous region cut by one narrow east-west valley and its tributaries from the north and south. The elevation varies from less than 1,000 to 4,000 feet. The district is occupied chiefly by old Paleozoic sediments interbedded with stills or flows of andesite and greenstone. Everywhere the sedimentary rocks strike northerly, usually about N 15 deg. E and dip eastward at angles ranging from 65 deg. nearly 90 deg. Diller has shown that Jurassic beds west of the district

11 Schrader, F. C., Stone, R. W., Sanford, Samuel, Useful Minerals in the United States: U. S. Geol. Survey Bull. 624, 1917, p. 193.

12 Kellogg, A. E., Cobalt in Jackson County, Oregon: Eng. and Min. Jour., vol. 112, Oct. 22, 1921, p. 650.

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have been overturned so that the oldest strata now overlie the younger formations. It is probable that the Paleozoic sediments are also overturned, and that limestone found in the district is probably of early Paleozoic age, and fossils found in limestone lenses indicate that they are not Devonian; Diller would suggest that they are Silurian rather than Carboniferous in age."

Pennsylvania.- Cobalt is reported as a constituent of the Cornwall iron ores. Tens of thousands of tons of cobalt element have been smelted in the iron blast furnaces, the cobalt content, of course, being partly lost in the slag and partly retained in the pig iron. The copper content of these ores has been recovered in recent years, but no information is available as to the possibility of saving the cobalt in a marketable form.

IMPORTS AND EXPORTS

Since the United States has produced very little cobalt, its fast growing consumption is reflected in the imports. The aggregate value of the cobalt imported annually in the form of ore, metal, and oxide has increased from a pre-war average of only $36,080 (average of fiscal years, 1909-1913, inclusive) to $2,680,200 in 1929. The imports of oxide have increased substantially, but the remarkable growth in imports under this general category is mainly attributable to the increased demand for cobalt metal. During the World War the demand for cobalt metal grew rapidly, but following the Armistice it dropped off abruptly with the result that imports of the metal in 1919 amounted to only 60,511 pounds. After increasing to 143,603 pounds in the boom year of 1920 they slumped again to 38,442 pounds in 1921. Since 1921, however, the imports have increased fairly steadily. The increase has been most marked in the last few years, the imports in 1929 being more than four times as great as those in 1925.

Even before the World War some cobalt metal was imported, but the quantities were combined in the statistics with the imports of ore. Both cobalt metal and cobalt ore have remained free of duty, whereas cobalt oxide has been dutiable for many years. Previous to the Tariff Act of 1913 the rate (25 cents per pound under the act of 1909) was sufficient to encourage the importation of cobalt metal free of duty for manufacture back into cobalt oxide. This situation was described by F. L. Merry of Swansea, England, in his testimony before the Ontario Nickel Commission: "The marketable stuff is cobalt oxide.* * * *. We used to reduce it to the metallic state and reburn it to the oxide. The black oxide, reduced to metal, will burn back black and the prepared oxide, reduced to metal, will burn back prepared."

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Zaffre, the impure oxide of cobalt obtained by roasting cobalt or ore speiss, also has been admitted free of duty. Under the Tariff Act of 1922, cobalt and cobalt ore are provided for in Paragraph 1550 and zaffre in Paragraph 1710 of the free list. Under Paragraph 29 of the same act, cobalt oxide is dutiable at 20 cents per pound; the sulphate and linoleate at 10 cents per pound; and all other cobalt salts and compounds at 30 per cent ad valorem.

During and shortly after the World War the imports of cobalt in various forms were derived almost exclusively from Canada, but later Belgium became of even greater importance as a source of supply, and since 1927 Australia has been contributing a rapidly increasing quantity. Germany, in addition to furnishing a part of the imports of oxide, is a source of practically all of the linoleate, sulphate, and other salts.

Table 2. - Cobalt ore, cobalt metal, and oxide and zaffre imported for consumption in the United States, 1901-1929

Year	Ore		Cobalt		Oxide		Total	
	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value
1901	- - -	- - -	- - -	- - -	- - -	- - -	1/ 71,969	1/$ 134,208
1902	- - -	- - -	- - -	- - -	- - -	- - -	1/ 79,984	1/ 151,115
1903	- - -	- - -	- - -	- - -	- - -	- - -	1/ 73,350	1/ 145,264
1904	- - -	- - -	- - -	- - -	- - -	- - -	1/ 42,354	1/ 86,925
1905	- - -	- - -	- - -	- - -	- - -	- - -	1/ 70,048	1/ 139,377
1906	- - -	- - -	- - -	- - -	- - -	- - -	2/ 41,084	2/ 83,167
1907	- - -	- - -	5,219	$ 1,821	42,794	$73,028	48,013	74,849
1908	- - -	- - -	217,548	13,982	1,550	3,095	219,098	17,077
1909	- - -	- - -	2,314	631	9,818	11,065	12,132	11,696
1910	- - -	- - -	8,811	1,546	6,124	4,806	14,935	6,352
1911	- - -	- - -	579,520	48,104	22,934	11,047	602,454	59,151
1912	- - -	- - -	759,394	67,948	31,848	15,132	791,242	83,080
1913	- - -	- - -	164,119	69,581	45,277	26,154	209,396	95,735
1914	- - -	- - -	106,670	53,945	227,886	220,593	334,556	274,538
1915	- - -	- - -	53,375	70,283	154,672	148,828	208,047	219,111
1916	- - -	- - -	136,770	175,236	206,639	192,009	343,409	367,245
1917	- - -	- - -	223,794	369,950	276,406	275,821	500,200	645,771
1918	3/- - -	3/ - -	504,391	628,099	208,596	291,699	712,987	919,798
1919	17,045	$2,832	60,511	141,450	131,424	184,751	208,980	329,033
1920	13,039	4,794	143,603	326,864	202,724	399,605	4/359,586	4/ 731,277
1921	7,657	3,325	38,442	105,539	164,003	342,426	210,102	451,200
1922	5,195	7,075	126,364	321,396	217,530	435,895	349,089	764,366
1923	58,719	56,326	225,639	552,434	258,574	511,903	542,932	1,120,663
1924	28,786	37,276	118,952	264,935	226,703	440,898	374,441	743,109
1925	34,782	31,320	192,669	422,185	287,265	546,292	520,716	999,797
1926	154,468	55,820	387,076	820,873	333,132	632,478	4/874,786	4/1,509,211
1927	60,382	3,019	407,198	841,442	369,747	703,608	837,327	1,548,069
1928	107,498	25,922	535,817	1,147,574	364,154	692,753	1,007,469	1,866,249
1929	434,443	51,862	806,640	1,743,465	475,928	884,873	1,717,011	2,680,200

1 Cobalt oxide, ore, and zaffre imported for the years 1901 to 1905, inclusive,
2 The imports for 1906, included 12,850 pounds of ore and zaffre.
3 Ore included with cobalt not separately recorded until July 1, 1918. From July 1 to Dec. 31, 1918, imports are recorded as follows: Ore, 220,115 pounds, valued at $55,188; metal, 250,920 pounds, $498,316.
4 Includes 220 pounds of zaffre, valued at $14, in 1920, and 110 pounds, valued at $40, in 1926. Imports of zaffre not separately recorded for 1918, and none imported in 1919, 1921, 1922, 1923, 1924, 1925, 1927, 1928, and 1929.

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Table 3. - Cobalt compounds (other than cobalt oxide) imported for consumption in the United States, 1922-1929[1]

Calendar Years	Linoleate		Sulphate		Other salts		Total	
	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value
1922	- - -	- - -	- - -	- - -	- - -	- - -	2/ 11	2/ $ 26
1923	3,617	$1,140	39,691	$24,597	2,336	$1,619	45,644	27,356
1924	40	22	- - -	- - -	757	834	797	856
1925	3,258	1,196	9,780	5,951	218	747	13,256	7,894
1926	2,522	952	34,466	20,163	354	532	37,342	21,647
1927	- - -	- - -	55,045	28,617	82	64	55,127	28,681
1928	- - -	- - -	68,150	39,791	131	202	68,281	39,993
1929	- - -	- - -	60,596	34,893	4,186	2,655	64,782	37,548

1 Figures on imports compiled by J. A. Dorsey, of the Bureau of Mines, from records of the Bureau of Foreign and Comestic Commerce.

2 Cobalt compounds, other than linoleate and sulphate, imported Sept. 22 to Dec. 31, 1922. Not separately classified prior to change in tariff.

THE INDUSTRY IN FOREIGN COUNTRIES

The Deloro Smelting and Refining Co. (Ltd.), recovering cobalt metal, oxides, and salts from arsenical-silver-cobalt-nickel residues from the Ontario silver mines, and the Union Minière du Haut-Katanga, in Belgium, producing cobalt and its oxides as a by-product from its copper ores mined in the Belgian Congo, are the dominant factors in the world's supply of cobalt in its various forms. In England, Henry Wiggin and Co. are important factors in the industry, and considerable cobalt is produced in Germany from residues and other by-products material. Other countries, notably Australia, have come forward in recent years as sources of cobalt ores, and cobalt occurrences of varying degrees of importance have been reported in many parts of the world. Since the advent of the Belgian Congo into the race, Canada's leadership in the industry captured from New Caledonia more than two decades ago has not been successfully challenged. The Belgian company's output, though a close second to that of the Canadian company, has never yet exceeded the output of the smelter in Ontario.

Before discussing the industry in the more important producing countries, brief mention may be made of a few of the minor occurrences. In South America cobalt is found in two countries, Chile and Argentina, but production is spasmodic and of no great importance.[13] In the Chilean Province, Atacoma, oxidized arsenical ore averaging 4 per cent cobalt has been worked. The chief mines are about 30 miles from the Port of Huasco, although veins of cobalt are found in the silver mines of this province as well as in Coquimbo and Santiago. The Argentine deposits are in Lar Rioja and Catamarca.

13 Min. Ind., 1921, vol. 30, p. 142.

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Cobalt minerals have been reported from various Mexican localities, chiefly as accessory minerals present in minor amounts. No important production has been reported. Erythrite has been found in Chihuahua and Jalisco, and wad containing cobalt has been reported in several States. Occurrences of cobaltite have been mentioned in Chihuahua, Durango, Jalisco, and Sinaloa. The arsenide, smaltite, is a constitutent of the ores of the Esmeralda mine in Jalisco, and the Pitmamo mine in Hidalgo.

In the British Isles cobalt minerals have been noted in the tin and copper lodes of Cornwall and, associated with arsenic, cobalt occurs in small amounts in the Peak district of Derbyshire, England. A small shipment of cobalt ore is said to have been made from the Muckross mine, Killarney, Ireland, linnaeite is reported in the coal measures of South Wales, and nickel cobalt ore has been found at Talnotry, Kirkcudbrightshire, Scotland.

In Czechoslovakia there are two areas, both in Bohemia. The metal-bearing veins of Pribram contain copper, lead, silver, arsenic, and antimony, and locally cobalt and nickel.[14] Cobalt, with nickel, tungsten, and uranium, is found in the Kaiserwald, in northwest Bohemia.[15]

During the latter part of 1927, discovery of cobalt in France, at Plombières, on the Arpen Plateau, was announced. A sample from the Plombières deposit showed 20 per cent cobalt.[16] Saxony was once an important producer of cobalt; now the small supply mined in that district is officially recorded as "cobalt-bismuth-nickel ores."[17] Sulitjelma, Norway, has yielded arsenopyrite crystals that contained from 0.98 to 1.32 per cent cobalt. Many years ago cobalt ore was mined for smalt (arsenic being a by-product) at the old smalt works of Modum, southern Norway. The ore forms fahlbands and is too poor to be mined with profit. Soil analyses from Pantchevo, near Belgrade, gave 0.0028 gram of cobalt and 0.0136 gram of nickel in a kilogram of earth.[18] H. Fehlmann, in the "Volkwirtschaftsdepartment Abteilung für industrielle Kriegswirtschaft Bergbaubureau, Bern, 1919," describes small deposits of cobalt at several places in Switzerland.

Belgium, in addition to producing cobalt from the Congo ores, contains a deposit of technical interest near Brussels where sand blackened in some places by manganese also contains cobalt in small amounts.[19] In Spain the Aramo mine near Pola de Lena, at La Saterrana, Asturias, and the Profunda mine, near Villamanin, Leon, have both produced cobalt. The former mine belonged at one time to the

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14 Slavik, F., The minerals of Pribram, Am. Mineralogist, vol. 12, No. 9, Sept., 1927, pp. 345-350.

15 Friesen, Anton, Erzvorkommen im Kaiserwaldgerbirge: Glückauf, Baud 64, Heft 2, Vienna, 1916, pp. 53-120.

16 Eng. and Min. Jour., vol. 125, Jan. 7, 1928, p. 31.

17 Hess, Frank L., Rare metals: Mineral Resources of the United States, 1927, Pt. II, Bureau of Mines, 1929, p. 394.

18 Bertrand, Gabriel, and Mokragnatz, , Sur la présence du cobalt et du nickel dans la terre arable: Compt. rend., vol. 175, 1922, pp. 112-114.

19 Cobalt in the sands of Woluwe-Saint-Lambert: Jour. Chem. Soc., vol. 70, pt. 2, London, 1896, p. 434.

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Fábrica de Mieres and the Profunda mine to the heirs of D. Ruperto Sanchez, but in recent years there have been rumors to the effect that one or both of these mines would be reopened by an English company. Russia has produced small amounts of cobalt. The chief deposit is in the neighborhood of the Kedabek copper mines, at Dashkessan, in the Government of Elizabethpol. Arsenical ore is here found in irregular pockets with epidote, garnet, and hornblende in a porphyritic rock, accompanied by magnetic iron ore and occasionally galena and zinc blende. An analysis of the mineral gave 18 per cent cobalt.[20] "Nickel and cobalt ores are found in Transbaikal territory, almost exclusively in silver-lead mines. There are unverified reports. . . .of occurrences of cobalt in the silver-lead mines of Petropavlovski, Blagodatski, Chalbuchinski, Mikhailovski, and Kultun."[21] Cobalt is one of the elements included in the monopoly granted the rare elements cartel, Rjedky Elementy.

In the Far East, China has been producing cobalt for centuries for use locally in ceramic glazes. At present the output, amounting to 200 to 300 tons annually, is shipped largely to the potteries in Kiangsi Province. It is mined in Yunnan in various localities, notably Pingi, Fuming, Sungming, Suntien, Chanyi, Anning, Lunan, Luchuan, Wanshaan, and Luishui. India, likewise, has cobalt deposits, and cobalt-nickel speiss is produced in Burma in small amounts. According to a British official report,[22] cobalt ore, locally known as "sehta," carrying 28 per cent of cobalt, has long been known to occur in the copper mines of Babai and Bagor, in the neighborhood of Khetri, Rajputana; Cobaltiferous matte (11 to 14 per cent cobalt) was reported from the copper mines of Kachipatar Argah, in Nepal; cobalt has been detected in the sulphide ores that occur near Arumanallur, in Travancore; a cobaltiferous wad from Olatura, in the Kalahandi State, yielded 0.82 per cent of cobalt oxide; linnaeite has been found in the copper ore of Sikkim; and erythrite occurs as a pinkish encrustation on the zinc-lead sulphide ore of the Bawdwin mines, in Burma.

Australia

Before the discovery of the Canadian deposits, Australia was second only to New Caledonia in the supply of cobalt. At that time the production came from the deposits at Port Macquarie which are similar to those of New Caledonia. As a result of the development of the cobalt-silver mines in Ontario production from this area, virtually ceased, but in 1921 Australia again began to produce cobalt in significant quantities from Queensland. After 1924 the output from this State dropped off rapidly and in 1927 there was no production recorded in Queensland. Shortly thereafter, however, Australia gain came forward as a minor factor in supply.

Small shipments of arsenical gold ore containing cobalt have been made from British Columbia to Australia, and undoubtedly ore and concentrates produced in New Caledonia are treated in Australian works from time to time.

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20 The Mineral Industry during 1919, vol. 28, p. 137.

21 Baievsky, Boris, Iron and Alloy Metals in Siberia: Bureau of Foreign and Domestic Commerce Trade Information Bull. 359, 1925, p. 27.

22 Imperial Mineral Resources Bureau, Cobalt (1913-1919): The Mining Industry, British Empire and Foreign Countries, War Period, 1921, p. 16.

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New South Wales.- At Port Macquarie cobalt-bearing wad associated with loosely cemented grains of chromite and containing as much as 7.48 per cent of cobalt oxide, occurs in serpentine and in the iron-bearing claims resulting from a decomposition of the same rock which intrudes the sedimentary formations, chiefly carboniferous sandstones.

Other deposits in New South Wales are at Carcoar, where the ore is glaucodot, or cobalt-bearing mispickel, containing 28 per cent cobalt oxide; at Bungonia, where the ore is cobalt-bearing manganese oxide, found as concretionary nodules and as the cementing material of a grit, which contains 3.25 per cent of cobalt and 0.38 per cent of nickel; and at Cobalt (near Torrington), where the ore has been treated principally for bismuth and wolfram, and where the tailing dumps resulting from this treatment contain about 6.15 per cent of cobalt.[23]

Queensland.- The principal mines are at Mount Cobalt in the Cloncurry district, 19 miles south of Selwyn, the nearest railroad station, which is 71 miles from Cloncurry. Cobalt there occurs in a vein, in places as much as 3 feet in thickness, along the contact of a diorite dike intruded into Silurian schists. The vein minerals are cobaltite, and various oxidation products include erythrite and also some asbolite (cobalt-bearing powdery manganese dioxide). Analyses of the ore (concentrates ?) show from 10 to 19.5 per cent of cobalt with relatively small amounts of gold and silver, and what is worthy of special comment, no nickel or copper. The arsenic content ranges from 9 to 28.3 per cent.[24]

At Sally's Creek, in the Cloncurry district, 50 miles north of Cloncurry and about 11 miles north of Koolamarra siding on the Cloncurry-Mount Cuthbert Railway, cobalt ore was discovered in 1924, and work was begun at the Queen Sally mine in 1925. Domestic water is obtained within half a mile of the mine, and abundant water is available in Cabbage-tree Creek, 2 miles north. Timber for shafts is within easy distance. The cobalt occurs[25] in lenses of black oxidized ore; assays as high as 28 per cent of cobalt have been obtained. The ore is associated with sulphides but is free from manganese and nickel.

E. C. Saint-Smith, Government Geologist of Queensland says:[26]

"The ore-bearing formation consists of a narrow belt of quartz schist, quartzite, and limestone (Cloncurry series) lying within an extensive mass of intrustive (?) highly schistose diorite apparently striking northwest-southeast, parallel with the ore body.

"Occasional occurrence of an earthy blue mineral simulating azurite through the ore is of interest; from tests of Geological Survey, there can be little doubt but that it is an unusual form of the ordinary pink hydrous arseniate (erythrine). Greenish-yellow iron silicate is present in small quantity."

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23 Dept. of Mines (New South Wales) Geol. Surv. Bull. 13, 1925, p. 11.
24 Reid, J. H., Cobalt in the Cloncurry District: Queensland Govt. Min. Jour., vol. 22, Jan. 15, 1921, pp. 12-14.
25 Min. Ind., 1925, vol. 34, p. 177.
26 Saint-Smith, E. C., Queen Sally Cobalt Mine, Koolamarra, Cloncurry Mineral Field: Queensland Govt. Min. Jour., vol. 26, July 15, 1925, p. 281.

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A promising prospect at Dugald River, 50 miles north of Cloncurry, was announced by the Queensland Government Mining Journal, vol. 34, p. 2, 1928, which reported also a lode carrying 40 per cent of copper and 17 to 18 per cent of cobalt at Loongana, 20 miles south of Cloncurry. According to the same journal (April 15, 1924), cobalt was discovered in an old copper dump at Redcap, Chillagoe field.

South Australia.- Cobalt ore, containing smaltite and other minerals, is found at Bimbowrie, near Olary, on the Broken Hill line. According to L. C. E. Gee,[27] who quotes Government geologists, "rich cobalt ores in considerable variety were found; a lot of shallow shaft and costeaning work has been done. . . .This Bimba Hill locality is, indeed, a curious and interesting one in the way of metals and minerals. Copper, cobalt, nickel, and silver-lead occur. . . .These deposits carrying cobalt are worthy of special attention from prospectors, for the reason that cobalt is a common associate of rich silver ores." H. Y. L. Brown[28] says: "Cobalt ores occur in crystalline limestone near granite dikes and schists, along the bedding planes in seams and pockets: erythrite, smaltite, cobaltite, and earthy cobalt (oxide-MnO_2 and Fe oxides). Assays run to 22 per cent cobalt."

Western Australia.- Cobaltiferous epsomite was discovered[29] during 1918-19 at Parkerville, in an efflorescence in the form of a soft, loose white powder (3 to 25 mm. thick), on the western wall of the municipal quarry. An analysis indicates that the efflorescence is essentially epsomite mixed with a small percentage of gypsum. The presence of appreciable amounts of cobalt, nickel, and copper sulphates co-crystallized with the magnesium sulphate is unique, the only other occurrence known to literature being that of Neusohl (Hungary).[30]

Parkerville is situated in the midst of the immense granite massif of the Darling Ranges; the granite is transversed by a network of large epidorite dikes and by pegmatite and quartz veins, with occasional narrow greenstone dikes of later date. The quarry has exposed large faces of epidorite and granite, both kaolinized near the surface.

Belgian Congo

The largest known deposits of cobalt, at least outside of Canada, are at Katanga near Elisabethville, Belgian Congo. The operating company, the Union Minière du Haut-Katanga, which was formed in 1906 to exploit a 60,000-square-mile area, is a joint corporation representing the Comité Speciale du Katanga and the Tanganyika Concessions (Ltd.), a British company. The Comité Speciale is a combination of big banking houses and the Belgian Government; it is said to control 40

27 Reports by the Chief Registrar of Mines; a review of mining operations in the State of South Australia during the half year ended Dec. 31, 1914, No. 21, 1915, pp. 27-29.

28 Brown, H. Y. L., Record of the Mines of South Australia: 4th ed., Adelaide, 1908, pp. 53,353, and 354.

29 Simpson, Dr. Edward S., Cobaltiferous Epsomite at Parkerville, Jour. and Proc. of the Royal Soc. of Western Australia, vol. 6, Pt. II, Perth, 1919-20, pp. 88-89.

30 Dana, E. D., 1889 ed., p. 644.

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per cent of the stock of the Union Miniere. The copper smelting works of the company are situated about 2 miles from Elisabethville on the Lufria River. At this plant there is a cobalt furnace in which the cobalt is "slagged off." The slag is then treated in electric furnaces at Panda, 80 miles away, producing a copper-cobalt-iron alloy which is sent to Colen, near Antwerp, for refining. The production of cobalt by the Union Miniere in 1928 rose to 400 tons, an increase of 50 tons as compared with the previous year. The company proposed to double its output in 1929.[31] The Union Miniere began to sell cobalt, at least on an extensive scale, only since the completion of its refinery in 1925. Previous to that, however, considerable cobalt was recovered in the electrolytic refining of its blister copper. Formerly this crude copper contained from 2 to 4 per cent cobalt and previous to 1914 much of it was refined at Hamburg. After the outbreak of the War in Europe, it went to the United States (first to the American Smelting and Refining Co. and later to the Nichols Copper Co.) but in recent years the cobalt content of this blister copper has declined to 0.10 or 0.12 per cent.

Little information has been furnished as to the nature or extent of the cobalt deposits. It is known, however, that deposits are extensive and that the cobalt occurs principally as linnaeite, together with heterogenite and possibly cobaltite. The cobalt is always associated with copper; at the Luisha mine the ore contains 9 per cent of copper and 9 per cent of cobalt. Ore containing less than 6 per cent of cobalt is mechanically concentrated previous to smelting.

Canada

Most of the cobalt produced in Canada is obtained by treating the complex arsenical ores from the Cobalt, South Lorrain, and Gowganda silver-mining districts. In addition to by-product cobalt, however, a certain amount of low-silver, high-cobalt ore is mined primarily for its cobalt content. The nickel-copper ores of the Sudbury district contain small amounts of cobalt, and the nickel produced therefrom in Canada is said to carry on the average 0.5 per cent cobalt. Since this cobalt is not deleterious for most purposes it is not necessary to remove it. Nickel produced in Wales by the Mond process is practically cobalt-free, but no figures are available showing the recovery of cobalt from the residues of this process. Cobalt has also been identified in the Michipicoten district in Ontario; The Pas Mineral belt, Manitoba, where cobalt minerals (chiefly smaltite and erythrite) occur with gold, lead, silver, and antimony; the property of the New Hazleton Cobalt Mines (Ltd.) on the west side of the Rocher de Boule Mountain, and more recently (1928) on Boulder Creek, in the Cowichan district, British Columbia.

Cobalt ore was first discovered in Canada in 1903 on the line of the Temiskaming and Northern Ontario Railway, about 100 miles north of North Bay. The name "Cobalt" was given to the district which has subsequently furnished by far the greater part of the world's upply of cobalt in addition to being the greatest silver producing area of the world for some 20 years. Geology of the Cobalt district has often been described, and for information as to the general character and origin of the vein formations the reader is referred to a report by Willet G. Miller.[32]

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31 Union Miniere Outputs: South African Min. and Eng. Jour., vol. 40, No. 1954, pt. 1, Mar. 9, 1929, p. 45.

32 Miller, W. G., The Cobalt-Nickel Arsenides and Silver Deposits of Temiskaming: Rept. of Canadian Bureau of Mines, vol. 19, Pt. II, 1913, p. 5.

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Production figures for Canada include the cobalt content of the various cobalt products sold by the south Ontario smelters added to the cobalt content of the ores and residues exported for treatment in foreign smelters; the value given is the net amount received by the shippers. In the earlier years cobalt-bearing ores low in silver were left in the mine or thrown on the dump, as the cobalt contents were of little or no value. In recent years, on the other hand, as the price of silver has declined and the demand for cobalt increased, the situation is beginning to change. Early in 1930, in fact, it was proposed to resume work at the old La Rose mine, a worked-out silver mine which is said to contain quantities of cobalt ore. Although at present the smelter at Doloro, Ontario, is the only plant in North America producing cobalt, cobalt oxides, and other compounds, cobalt has also been recovered by the Coniagas Reduction Co. of Thorold; by the Canadian Refining and Smelting Co. at Orillia; by the Canadian Copper Co. (International Nickel) at Copper Cliff; and the Metals Chemical Co. at Welland. The last of these smaller plants (Thorold) ceased operations in 1926.

From 1907 until April, 1917, the Metal Refining Bounty Act was in operation. Under this act, bounties were paid to refineries on cobalt metal, cobalt oxide, and salts of cobalt, and also on nickel oxide and salts of nickel. The bounty was at the rate of 6 cents per pound on the metallic content.

Table 4. - Total shipments from Ontario silver mines, smelters, and refineries, 1904 to 1929[1/] [2/]

Year	Short tons	Value	Year	Short tons	Value
1904	16	$ 19,960	1918	380	$1,640,310
1905	118	100,000	1919	298	1,019,479
1906	321	80,904	1920	283	1,605,365
1907	739	104,426	1921	126	616,235
1908	1,224	111,118	1922	3/776	1,333,676
1909	1,533	94,965	1923	380	1,803,872
1910	1,098	54,699	1924	476	1,662,526
1911	852	170,890	1925	558	2,328,517
1912	934	314,381	1926	332	1,136,014
1913	821	420,386	1927	440	1,764,534
1914	351	590,406	1928	477	1,671,900
1915	206	383,261	1929	465	1,801,915
1916	400	805,014	Total[4/] ?	13,941	$22,772,743
1917	337	1,138,190			

1 Annual Reports of the Ontario Dept. of Mines. Toronto.
2 Cobalt metal and metallic contents of all cobalt compounds and cobalt in ores and speiss residues exported.
3 Includes 460 tons of speiss residues worth $153,116.
4 Preliminary.

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Table 5. - Cobalt products marketed by Ontario refineries, 1923-1925[1]

	1923[2]	1924	1925
Cobalt oxide-pounds	454,772	450,038	575,580
Cobalt in residues	88,090	(3)	(3)
Cobalt salts	71,093	61,908	100,483
Cobalt-nickel oxides, unseparated	226,328	271,179	164,901
Cobalt, metallic	227,993	174,349	625,298
Total value	$1,928,562	[4] $1,421,826	[5] $2,328,517

1 Annual Reports of the Ontario Dept. of Mines, Toronto. (After 1925 the various products are not segregated).

2 In 1923 the values of the various products are given separately. The average value per pound for the respective items were as follows: Oxide, $1.94; residues (cobalt contents) $2.50, salts, $0.88; unseparated oxides, $0.84; and metal, $2.52.

3 Not listed separately.

4 Exclusive of value of cobalt in 60,044 pounds of base bullion, speiss, and blast furnace cleanings valued at $87,263.

5 Exclusive of value of cobalt in 1,239,476 pounds of base bullion and speiss residues valued at $347,834.

New Caledonia

There is no accurate account of the history of cobalt mining in the island of New Caledonia, but the first claim was taken up in 1876, and the first official export figures are for the year 1888. Thenceforth the island was the chief producer of cobalt until the discovery of the Canadian mines, after which the industry languished. Production in recent years has been small and very irregular. Since 1909 no mine of importance has been worked, only small deposits under special conditions.

Cobalt in the form of asbolite occurs in bluish-black nodules in ferruginous clay derived from the weathering of serpentine formations which overlie a large part of the island. The cobalt deposits though numerous are never large, and they are distributed very irregularly. The cobalt oxide content averages between 4 and 6 per cent, but production costs are apparently too high to permit production to be maintained in competition with Canada and the Belgian Congo. Former centers of exploitation, most of which might again produce cobalt if prices rose sufficiently, are the followirg: Ounia, Boandy, Nemeni, Bogota, Canala, Moneo, Mou, Wagap, Geyeto, Voh, Gatope, Thie baghi, Vande, Pam, and Belep.

South Africa

Cobalt mines have been worked from time to time in various parts of British Africa. Work has recently been resumed at the Kruis River mine, which was operated about 1875 by a German, Carl Maunch, who is said to have sold £25,010 worth of hand-picked ore. As a result of the Secocoeni it was not reopened. Developments in 1929 were described as follows:

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"Some months ago we anticipated the formation of a company to exploit certain arsenide and oxide deposits of cobalt on the farm Kruisrivier, in the Middleburg district, which has been favorably reported on by Mr. W. F. H. Dudgeon, A.R.S.M. In view of the fact that the market value of the concentrates to be produced was not definitely known, a small private company, Cobalt (Proprietary), Ltd., has been formed to test this point. A small plant has already been put up, and it is expected that a trial shipment will be ready before the end of the present month. The deposits contain, in addition to arsenide and black oxide of cobalt, appreciable values in gold and some platinoids. Although nothing more than rumors of this activity can have reached Europe, considerable interest has already been evinced, judging from the letters of inquiry already received through consuls, trade commissioners, and other sources. This interest suggests that the views we have previously expressed as to the value of cobalt ores of fair content are not unduly optimistic."[33]

Another well-known occurrence of cobalt is at Laatse Grift No. 82, a few miles west of Kruis River. At Waaikraal, cobalt is found in appreciable quantities at the mine of the Edwards Goldfields, in the Rustenburg district, about 25 miles northeast of Rustenburg and about 42 miles northwest of Pretoria. In 1926 the main shaft at the property was down 160 feet on the incline, and work had been done along the strike for a distance of 450 feet. Assays of this ore showed a range in cobalt content from 3.95 per cent to 9.7 per cent. The ore is arsenical, the cobalt probably being in the form of smaltite, and some of it contains as much as 53 ounces of gold. Other occurrences of cobalt have been reported on the farm Wenzam Leid, situated some 2 miles south of Balmoral station on the Pretoria - Delogoa Bay Railway and in small amounts in the central part of the Bushveld igneous complex.

MARKET GRADES

Cobalt metal is marketed in three forms - rondelles, shot, and anodes. The production of anodes for cobalt plating is small and only a small amount of the highest-grade metal is produced as water-formed shot. Practically all of the metal is cast into rondelles, which are slugs about 1 inch in diameter and three-fourths inch thick. These rondelles are often shipped in bags but they are also packed in small casks, particularly for export trade.

Cobalt oxide is marketed either as black or gray oxide; the black oxide contains about 70 per cent cobalt metal, and the gray about 75 per cent. Gray oxide is made by roasting the black oxide slightly in a reducing atmosphere in a reverberatory furnace.[34]

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33 Money and Mines; Cobalt Activity: South African Min. and Eng. Jour., vol. 40, Aug. 10, 1929, p. 657.

34 Dominion Bureau of Statistics, Annual Report on the Mineral Production of Canada, 1926: Ottawa, 1928, p. 136.

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The following table listing the customary brands of cotalt compounds with their cobalt content has been taken from Drury:[35]

Table 6. - Brands of cobalt compounds, showing their cobalt content

Brand	Special designation	Chemical formula	Percentage cobalt content
F F Ko ...	Finest cobalt oxide (superior oxide).	CoO	1/ 78
G K O ...	Grey cobalt oxide, Ia	CoO	1/ 76
F K O ...	Grey cobalt oxide	CoO	1/ 75
R K O ...	Black cobalt oxide, Ia	Co_2O_3	1/ 70
S K O ...	Black cobalt oxide	Co_3O_4	1/ 66
A K O ...	Cobalt arsenate	$Co_3As_2O_8.8H_2O$	29
K O H ...	Cobalt carbonate	$CoCO_3$	50
P K O ...	Cobalt phosphate	$Co_3(PO_4)_2.8H_2O$	34

1 Theoretically CoO, Co_2O_3, and Co_3O_4 contain 78.8, 71.1, and 73.4 per cent cobalt, respectively.

The oxide, since it is a powder, is shipped in barrels; special tin containers holding 5, 10, and 25 pounds are required for the Japanese trade. According to Bateman:[36]

"The marketability of cobalt ores depends not only upon the grade but upon the other associated minerals. Arsenic is an important and desirable constituent of the ore, but the higher the nickel content, the less desirable the ore is, as the nickel must be separated, and the expense is generally greater than the value of the metal recovered. This applies to practically all associated minerals, with the exception of arsenic and silver. On this continent it is almost impossible to market an ore for cobalt if such ore contains any considerable quantity of lead, zinc, and copper. An ore containing less than 4 per cent of metallic cobalt is not acceptable to the smelters.

"Cobalt ore is being marketed in America in four different forms:

1. Hand-sorted silver ore and sand-table concentrates, carrying high silver values and running generally between 5 and 8 per cent metallic cobalt.

2. Massive cobalt ore carrying low silver values and running between 6 and 12 per cent metallic cobalt. Ores of this sort contain approximately 60 per cent arsenic.

3. Residues from the cyanide treatment of high-grade silver ores and concentrates, carrying 5 to 8 per cent cobalt, and up to 50 ounces of silver.

35 Drury, Charles W., Cobalt, its Occurrence, Metallurgy, Uses, and Alloys: Rept. Ontario Bur. Mines, 1918, vol. 27, pt. 3, p. 84.

36 Bateman, G. C., Marketing of Cobalt Ores and Metal: Eng. and Min. Jour., vol. 116, Dec. 22, 1923, pp. 1076-1077.

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4. Speiss from American smelters, treating silver-cobalt ores and generally containing large percentages of iron, copper, and lead."

PRICES

The prices of cobalt metal and oxide are fixed at infrequent intervals by a few producers acting virtually in agreement and in accordance with general trade conditions. Drastic reductions in prices have followed the advent of each new producer into the market but as these successive increments of supply are absorbed equilibrium is reestablished more or less promptly. In recent years demand has increased rapidly and fairly steadily, but not yet does it appear to be of a character that will respond readily to changes in price. It is reasonable to suppose that a large increase in price would tend seriously to curtail consumption, but it does not follow that a sudden drop in price would tend rapidly to increase demand. In any event the history of the industry reveals the policy of producers in recent years to adjust the supply to meet the demand, keeping prices meanwhile at as nearly a uniform level as possible.

Formerly very rare and expensive, cobalt compounds became relatively cheap when the new Caledonian ore came upon the market. In the eighties cobalt oxide, 170 per cent, generally sold at about $2 a pound, and for many years the price remained between $1.60 and $2 a pound. In 1909 it jumped to $2.50 only to drop to $1.40 in 1909, and as larger and larger quantities of cobalt recovered from the silver ores of Ontario came upon the market some oxide was sold as cheap as 50 cents a pound in 1912. The magnitude of this second upheaval in the supply situation is evident from the fact that in 1910 the estimated world consumption of cobalt oxide was in the neighborhood of 300 tons, whereas fully 1,500 tons could have easily been recovered from the silver ores mined in the Cobalt camp in that same year. Cobalt remained a drug on the market until after 1915. Conditions improved as a substantial demand began to be created for the metal, and in consequence the price of the oxide advanced from around 90 cents in 1915. In 1917 black oxide advanced from $1.05 a pound to $1.50 a pound and gray oxide from $1.15 to $1.65. These prices were fairly well maintained, despite the advent of production from the Missouri Cobalt Co., until 1920 when the price rose to $2 and finally at the height of the boom to $4.10. In 1921, in spite of a weak demand, the oxide was quoted at approximately $3; the price declined, in the following year to about $2.25, where it has virtually remained ever since. In the early part of 1930, according to the Engineering and Mining Journal, black oxide, 70 per cent, was quoted at $2.10 a pound, f. o. b. Canadian works, and the London quotations were 8s. ($1.95) for black oxide and 8s.10d. ($2.15) for gray. Black oxide has generally ranged in price from $2 to $3 a pound.

Cobalt metal as far back as 1901 was purchased by Krupp at prices ranging from 7s.6d. to 10s.6d. a pound ($1.83 to $2.56).[37] Subsequently, in view of the fact that reduced oxide was imported into the United States in order to evade the

37 Merry, F. L., Testimony before Ontario Nickel Commission: 1917, Appendix, p.

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the duty of 25 cents a pound on oxide,[38] it is evident that the metal, at least in this form, was about as cheap as the equivalent weight of oxide, and for a time after Canadian metal began to make its appearance it was sold for about $1 a pound. In 1917, however, the price rose rapidly from $1.25 to $2.25, and in 1920 it advanced from $3 to $6 a pound. After remaining around $3 a pound from 1921 to 1923, it receded gradually to $2.50. Early in 1930 this was the nominal price quoted by the Engineering Mining Journal for shot or rondelles (97 to 98 per cent) f. o. b. Canadian works. Contract sales, of course, are booked at discounts, down to about $2.10 and under special circumstances perhaps below $2 a pound. The London quotation has remained at 10s. ($2.43) a pound almost continuously since 1923.

Quotations for cobalt and cobalt oxide have appeared with sufficient regularity to permit of tabulation only in recent years. The available figures are presented in the following table:

Table 7. - New York and London prices per pound of cobalt metal, gray oxide, and black oxide 1929[1]

	NEW YORK			LONDON		
	Metal	Gray oxide	Black oxide	Metal	Gray oxide	Black oxide
1913	(2)	(2)	(2)	(2)	(2)	(2)
1914	(2)	- -	-	-	-	-
1915	(3)$1.60-$1.70	(2)	(2)	-	-	-
1916	1.25- 1.50	(2)	(2)	-	-	-
1917	1.25- 2.25	$1.15-$1.65	$1.05-$1.50	-	-	-
1918	2.25- 2.50	1.65 -	1.50 -	-	-	-
1919	2.50- 3.00	1.65 -	1.50 -	-	-	-
1920	(4) 2.50- 6.00	- -	(5) 2.00- 4.10	-	-	-
1921	3.00- 6.00	- -	2.00- 4.10	-	-	(2)
1922	3.00- 3.25	- -	2.00- 2.10	(2)	(2)	(6)11s.-12s
1923	2.65- 3.00	- -	2.00- 2.25	11s.-12s.	10s. -	9s. -
1924	3.00- 3.50	- -	2.10- 2.25	10s.-11s.	- -	9s. -
1925	2.50- 3.00	2.25- 2.35	2.10- 2.25	10s.- -	(7) 8s.10d.-	8s. 9s
1926	2.50- 2.75	2.20- 2.35	2.10- 2.20	10s. -	8s.10d.-	8s. -
1927	2.50- 2.60	- -	2.10 -	8s.6d.-10s.	8s.10d.-	8s. -
1928	2.50- 3.00	- -	2.10 -	9s.6d.-10s.	8s.10d.-	8s. -
1929	2.10- 3.00	- -	2.10 -	10s. -	8s.10d.-	8s. -

1 Prices for the years 1915-1919 are quoted from the Mineral Industry as also for 1925 and 1926 for gray oxide. For the years 1920-1929 prices are quoted as follows: Metal, shot or rondelles, 96 and 98%, f.o.b. Canadian works; black oxide, 70%, f.o.b. Canadian works, from the Engineering and Mining Journal.
2 Not quoted.
3. Quotation in August, 1915.
4 Quotations from April to December, 1920.
5 Quotations from May to December, 1920.
6 Quotation for month of December, 1922.
7 Quotations from August to December, 1925.

38 As noted under "Imports" on p. 13.

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The market for cobalt-bearing ores and residues has improved markedly in the last two or three years. The principal sources of cobalt shipped to Deloro, Ontario, is still the high-silver ore and concentrates. On this class of material the shipper is paid for 98 per cent of the silver and, provided the ore assays over 5 per cent of cobalt, for the total contents of cobalt metal. The price paid for the cobalt is 2 cents per unit per pound, equivalent for a 5 per cent ore to 10 cents a pound and for a 10 per cent ore to 20 cents a pound of cobalt content. The smelter charge is $20 a ton, and a further deduction of one-half cent an ounce of silver is made for refining. Freight charges are paid by the shipper.

In order to encourage the mining of low-silver high-cobalt ores, the Deloro company issued in 1928 a special tariff covering ores containing 8 per cent or more of cobalt and less than 500 ounces of silver per ton. In ores containing under 100 ounces of silver no payment is made for the silver, the price for the cobalt is $90 a ton, provided the ore contains over 8 and less than 9 per cent of cobalt. As there is no separate smelting charge, this works out to about 50 cents a pound of metallic cobalt contained in the ore; but for each additional 1 per cent of cobalt, the price advances $15 per ton (gross weight) or 75 cents per pound of cobalt content. On ores containing between 100 and 500 ounces of silver per ton, 90 per cent of the silver content is paid for, and the cobalt is paid for at the rate of 3 cents per unit per pound. In the latter case, therefore, payment per pound of cobalt content is at the rate of 24 cents for an ore containing 8 per cent and 30 cents if it contains 10 per cent.

No payment is made for the arsenic, although this is recovered as a by-product in the smelting operation.

Since the Ontario ores contain silver, nickel, and arsenic as well as cobalt, they have to be treated by a relatively complicated series of processes, and for that reason the price paid for the cobalt contents by the Canadian smelting company is lower than that offered by European smelters for less complex ores. At present (May, 1930) as much as $1 a pound of metallic content would be paid by certain dealers f. o. b. New York for ore containing even as much as 5 per cent of cobalt and relatively free from objectionable elements such as nickel or arsenic. Even the arsenical ores from Cobalt, Ontario, command as much as $400 a ton or $1 a pound of cobalt content, provided they carry as much as 20 per cent of the metal. Ore containing 15 per cent has been sold for $225 a ton or $0.75 a pound of metal content, f. o. b. Cobalt.

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NORTH AMERICAN BUYERS OF COBALT ORES OR RESIDUES

Deloro Smelting and Refining Co., Deloro, Ontario, Canada.
Harshaw Chemical Co., Cleveland, Ohio.
Charles Hardy, Inc., 122 East 42d Street, New York, N. Y.
Metal & Ore Corporation, Woolworth Building, New York, N. Y.
Electro Metallurgical Co., 30 East 42d Street, New York, N. Y.
Hugo Falck & Co., 25 Broadway, New York, N. Y.
Jungmann & Co., Inc., 3 Desbrosses Street, New York, N. Y.
Shepherd Chemical Co., Highland Avenue, Norwood, Cincinnati, Ohio.
J. A. Samuel & Co., 220 Broadway, New York, N. Y.
Simonds Saw and Steel Co. (F. B. Lewis, Manager), 85 First Street, Portland, Ore.

BRITISH BUYERS OF COBALT AND COBALT SALTS[39], LONDON

W. Adolph & Co., (Ltd.), 135 Upper Thames Street, E.C.4.
A. Boaks, Roberts & Co. (Ltd.), 100 Carpenters Row, Stratford, E. 15.
Chance & Hunt (Ltd.), 61 Grace Church Street, E.C.3.
The General Commercial Co. of London (Ltd.), 114 Cannon Street, E.C.4.
Hickie, Borman & Woods (Ltd.), 36 Lime Street, E.C.3.
Leopold Lazarus, 11-13 Creechurch Lane, E.C.3.
Edward Le Bas & Co., Dork House, Billiter Street, E.C.3.
Sanders, Page & Co., 90 Fenchurch Street, E.C.3.
Donald A. Scott & Co. (Ltd.), 10 Arthur Street, E.C.4.
Metal Traders (Ltd.), 7 Grace Church Street, E. C. 3.

39 As furnished by the Chief Canadian Trade Commissioner in 1922. Published by the Mines Branch, Ottawa, Canada. Paper No. 8.

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